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# Cost–benefit analysis for optimal DG placement in distribution systems by using elephant herding optimization algorithm

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## Abstract

Distributed generations (DGs) are small generating plants which are connected to consumers in distribution systems to improve the voltage profile, stability improvement, reduction in power losses and economic benefits. The above benefits can be achieved by optimal placement of DGs. In this paper, a novel nature-inspired algorithm called elephant herding optimization algorithm is used to determine the optimal distributed generation size. It has been developed based on herding behaviour of elephant groups in nature. The proposed algorithm is tested on IEEE 15-, 33- and 69-bus test systems. The proposed algorithm with type III DG unit operating at 0.9 pf gives better results when compared with other methods in the literature.

**Keywords:** Elephant herding optimization algorithm, Power loss reduction method, Distributed generation placement, Radial distribution system, Loss reduction

## Introduction

Distributed generation concept was aroused when the electricity was introduced as a commercial alternative for the energy. In distribution systems, the power flow is unidirectional and has radial structure. As the demand is increasing day by day, it faces several problems. About 70% losses are occurring at distribution level, while 30% losses are occurring at transmission level. Hence distribution systems are main concern nowadays. The losses targeted at distribution level are about 7.5%. Generally power sources like distributed generations (DGs), capacitor banks, etc. are used to reduce losses. Quite a lot of methods have been proposed in the literature for the placement of DGs.

To minimize line losses of power systems, it is crucially important to define the size and location of local generation to be placed. Proper location of DGs in power systems is important for obtaining their maximum potential benefits. The authors Zhang et al. (2018), Acharya et al. (2006) and Wang and Nehrir (2004) proposed an

analytical expression to calculate the optimal size and an effective methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses in primary distribution systems.

The authors Kaur and Jain (2017) proposed the optimal placement of multiple dispersed generators using multi-objective optimization. A new planning approach based on voltage stability index (VSI) together with improved loss minimization (LM) formulations was also presented in the literature (Kazmi and Shin 2017; Singh and Parida 2016; Singh and Goswami 2009; Kayal and Chanda 2013; Aman et al. 2012, 2013, 2014; Amanifar 2011; Hedayati et al. 2008).

The optimal placement and sizing of distributed generators for real power losses minimization in distribution systems over the past years were proposed with different algorithms called war optimization (Coelho et al. 2018), global criterion method (Bhattacharya et al. 2018), hybrid GMSA (Mohamed et al. 2018), a multi-objective evolutionary algorithm based on decomposition (MOEA/D) (Biswas et al. 2017), K-means clustering method (Penangsang et al. 2018), shuffled frog leaping algorithm (SFLA) (Suresh and Belwin Edward 2017), a combination of a fuzzy multi-objective approach and bacterial foraging

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optimization (BFO) as a meta-heuristic algorithm is used to solve the simultaneous reconfiguration and optimal sizing of DGs and shunt capacitors in a distribution system (Mohammadi et al. 2017), a multi-objective genetic algorithm (Tarôco et al. 2016), grey wolf optimizer (GWO) for multiple DG allocation (i.e. siting and sizing) in the distribution system (Sultana et al. 2016), shuffled bat algorithm (Yammani et al. 2016a), hybrid optimization algorithm (Yammani et al. 2016b), flower pollination algorithm (Sudabattula and Kowsalya 2016), hybrid big brunch big crunch algorithm (Saha and George Fernandez 2016), sensitivity analysis technique (Gopiya Naik et al. 2013), a modified teaching–learning-based optimization (MTLBO) algorithm (Martín García and Gil Mena 2013), harmony search algorithm (HSA) (Rao et al. 2013), combined genetic algorithm (GA)/particle swarm optimization (PSO) (Moradi and Abedini 2012), improved honey bee mating optimization (HBMO) algorithm (Niknam et al. 2011), multi-objective index-based approach (El-Zonkoly 2011), particle swarm optimization (PSO) (Táutiva et al. 2009; Kansal et al. 2013), a genetic algorithm (Masoum et al. 2004) capacitor placement, multi-objective particle swarm optimization (MOPSO) probability-based solar power DG into the distribution system (Mahesh et al. 2017a, b), state-of-the-art models and methods applied to the ODGP problem (Georgilakis and Hatziargyriou 2013; Abdulwahhab Abdulrazzaq et al. 2016; Warid et al. 2017) and a binary particle swarm optimization (BPSO) algorithm (Moshtagh et al. 2010).

Several performance evaluation indices such as active and reactive power loss indices, voltage deviation index, reliability index and shift factor indices are used to develop a novel multi-objective function (MOF). A novel MOF has been solved to find optimal sizing and placement of DGs using genetic algorithm, and particle swarm optimization technique was proposed in Bohre et al. (2016). Optimal allocation and operating point of DG units in radial distribution network considering load pattern had done in Sultana et al. (2017) and Hadavi et al. (2017). The authors Kalambe and Agnihotri (2014), Viral and Khatod (2012) and Li et al. (2018) give a bibliographical survey, general background and comparative analysis of three most commonly used techniques: (i) capacitor placement, (ii) feeder reconfiguration and (iii) DG allocation for loss minimization in distribution network.

Optimal and simultaneous siting and sizing of distributed generators and capacitor banks in distribution systems have attracted a lot of attention from distribution companies (Pereira et al. 2016). Techno-economic analysis is important in DG placement. Some of the papers (Tanwar and Khatod 2016, 2017; Muttaqi et al. 2016; Asadi et al. 2014; Mousavi and Mohammadi 2011; Payyala and Green 2006) address the issue of DG planning and has proposed

different techniques for optimizing the DG size and location to minimize the overall investment and operational cost of the system. The installation of distributed generation power plants is common due to advantages such as system capacity release, voltage support and reduced energy losses in power networks (Dorahaki 2016). The authors Ameli et al. (2015) propose a novel comprehensive economic method for planning DG units which considers both the distribution company's (DisCo) and the DG owner's (DGO) profits simultaneously. The authors Kansal et al. (2017) present an profit/worth analysis approach for DG placement.

To the best of authors' knowledge, elephant herding optimization has not been proposed to optimal DG size with economic analysis in the literature.

### Problem formulation

In the distribution system, more losses are there due to low voltage compared to transmission system. Copper losses are predominant in distribution system and this can be calculated as follows

$$P_{\text{loss}} = \sum_i^{n-1} I_i^2 R_i \quad (1)$$

where  $I_i$  is current,  $R_i$  is resistance and  $n$  is number of buses. Objective taken in this paper is real power loss minimization. The voltage constraint is between the limits 0.9 to 1.05. The upper and lower limits of DG are 60 to 3000, where the limits are in kW, kVAR and kVA for type I, II and III DG, respectively.

### Power loss reduction method

DG locations are obtained based on the power losses and their loss reductions in the system (Dinakara Prasad Reddy et al. 2018). Artificial intelligence technique is not involved in this method. The loss reductions at all the buses are calculated by compensating the total reactive power at each bus. The obtained loss reduction values are normalized into the range [0, 1] for simplification, and minimum and maximum loss reductions are noted (Dinakara Prasad Reddy et al. 2018).

Real power loss in the  $k$ th line is given by  $[I_k^2] \times [R_k]$  and can also be expressed as follows

$$PL(j) = \frac{(P^2(j) + Q^2(j)) \times R_k}{V(j)^2} \quad (2)$$

Similarly reactive power loss in the  $k$ th line is given by  $[I_k^2] \times [X_k]$  and can also be expressed as follows

$$QL(j) = \frac{(P^2(j) + Q^2(j)) \times X_k}{V(j)^2} \quad (3)$$

**Table 1** PLI values for 15-bus system

PLI values	Bus number
1.0000	15
0.9865	11
0.9602	4
0.8353	7
0.8000	6
0.4611	12
0.4119	14
0.3266	8
0.3205	3

where  $I_k$  is the current flowing through  $k$ th line.  $V[j]$  is the voltage at the bus ' $j$ '.  $P[j]$  = net active power supplied beyond the bus ' $j$ '.  $Q[j]$  = net reactive power supplied beyond the bus ' $j$ '.  $R_k$  and  $X_k$  are the resistance and reactance of the  $k$ th line.

After finding the real and reactive power losses for all the buses, the loss reduction factors can be calculated using the following equation.

$$PLI(b) = \frac{LR(b) - LR(\min)}{LR(\max) - LR(\min)} \quad (4)$$

where  $b$  is the number of the bus.  $LR(b)$  is the loss reduction at bus  $b$ .  $LR(\min)$  and  $LR(\max)$  are the minimum and maximum loss reduction values. Power loss index (PLI) represent the loss reduction of that particular bus with respect to the maximum and minimum loss reductions in the system so that when the DGs are placed on the buses with high power loss index, maximum loss reduction can be expected.

#### Optimal locations for 15-bus system

The proposed PLR method is applied to IEEE 15-bus system. Optimal locations are identified based on the PLI values (Table 1).

First best location for 15-bus system is 15.

#### Optimal locations for 33-bus system

The proposed PLR method is applied to 33-bus system. Optimal locations are identified based on the PLI values (Table 2).

Best location for 33-bus system is 30.

#### Optimal locations for 69-bus system

The proposed PLR method is applied to 69-bus system. Optimal locations are identified based on the PLI values (Table 3).

First best location for 69-bus system is 61.

**Table 2** PLI values for first ten elements of 33-bus system

PLI values	Bus number
1.0000	30
0.2176	32
0.1531	31
0.1371	29
0.1317	14
0.1283	8
0.1195	7

**Table 3** PLI values for first ten elements of 69-bus system

PLI values	Bus number
1.0000	61
0.2669	64
0.1018	59
0.0736	65
0.0570	21
0.0547	12
0.0494	11

## Elephant herding optimization

### Herding behaviour of elephants

African and Asian elephants are two of traditionally recognized species of the one of the largest mammals on earth. Multi-purpose usage of the long trunk of elephant like breathing, sucking water and fetching objects had the most significant feature. Elephants are social animals where females and calves live together as a herd. Different clan elephants are present in the group where the oldest leads them. A clan consists of one or more females with their kids. Females live in groups, and males live separately; they leave the family group after growing group. Through low-frequency vibrations, the male elephants maintain contact with female elephants in the clan. In this paper, for the formation of general-purpose global optimization method, two operators are derived from the herding behaviour of the elephants (Wang et al. 2015).

### Elephant herding optimization

Three common rules are formed from the herding behaviour of the elephants to solve all types of global optimization problems.

1. The elephant population is composed of some clans where each of the clan has fixed number of elephants.

2. In each generation, a certain number of male elephants live unaccompanied leaving their family group or herd.
3. A matriarch acts as the leader for elephants living in a clan.

### Clan updating operator

As the elephants live together under the leadership of the matriarch, the next position of each of the elephant is dependent on the matriarch of the clan. In clan for elephant  $j$ , it is given as

$$x_{new,ci,j} = x_{ci,j} + \alpha \times (x_{best,ci} - x_{ci,j}) \times r \quad (5)$$

where for elephant  $j$  in clan  $ci$ ,  $x_{new,ci,j}$  and  $x_{ci,j}$  are newly updated and old positions, respectively. The influence of the matriarch in  $x_{ci,j}$  is taken on a scale factor  $\alpha \in [0, 1]$ . The fittest elephant in the clan is  $x_{best,ci}$ . Uniform distribution is used in this algorithm and  $r \in [0, 1]$ . The equation for updating the fittest elephant matriarch is given below

$$x_{new,ci,j} = \beta \times x_{centre,ci} \quad (6)$$

The factor that influences the  $x_{centre,ci}$  on  $x_{new,ci,j}$  is  $\beta \in [0, 1]$ . From the information collected from all the elephants in the clan  $ci$ , the new member  $x_{new,ci,j}$  is generated in the clan. For the  $d$ th dimension having  $x_{centre,ci}$  as the centre of the clan, it is calculated using

$$x_{centre,ci,d} = \frac{1}{n} \times \sum_{j=1}^{n_{ci}} x_{ci,j,d} \quad (7)$$

The  $d$ th dimension has the limits  $1 \leq d \leq D$ , where  $D$  is its total dimension. The number of elephants in the clan is given by  $n_{ci}$ .  $d$ th elephant individual is given by  $\sum_{j=1}^{n_{ci}} x_{ci,j,d}$ . The centre of clan  $x_{centre,ci,d}$  is calculated from the above equation. The clan updating operator can be formulated as shown in Algorithm 1.

**Algorithm 1:** Pseudo code of clan updating operator

```

1 foreach ci=1 to nclan (for all clans in elephant population) do
2   foreach j=1 to nci (for all elephants in clan ) do
3     update equation  $x_{ci,j}$  and generate  $x_{new,ci,j}$ 
4     if  $x_{ci,j} = x_{best,ci}$  then
5       Update  $x_{ci,j}$  and generate  $x_{new,ci,j}$  by Eq.(6)
6     end
7   end
8 end

```

### Separating operator

After reaching puberty, the male elephants will leave their family group and live solitarily. While solving optimization problems, a separation operator can be modelled for this separating process. It is assumed that the elephant

individuals with least fitness will implement the separating operator for further improvement in search ability of EHO algorithm and is calculated as

$$x_{worst,ci} = x_{min} + (x_{max} - x_{min} + 1) \times rand \quad (8)$$

where the upper and lower bound positions of elephants are  $x_{max}$  and  $x_{min}$ , respectively. The worst elephant individual of clan  $ci$  is given by  $x_{worst,ci}$ . The uniform distribution is in the range  $[0, 1]$  and stochastic distribution which is given by  $rand \in [0, 1]$ . The separating operator can be formed as shown in Algorithm 2.

**Algorithm 2:** Pseudo code of separating operator

```

1 foreach ci=1 to nclan (for all clans in elephant population) do
2   Replace the worst elephant in clan ci by Eq.(8).
3 end

```

EHO method is developed and updated based on the description of clan updating operator and its mainframe is shown in Algorithm 3.

**Algorithm 3:** Pseudo code of EHO algorithm

```

1 Initialization. Set generation counter t=1 ; initialize the population;
  the maximum generation maxgen.
2 while t < maxgen do
3   Sort all the elephants according to their fitness.
4   Implement clan updating operator by algorithm 1.
5   Implement separating operator as shown in algorithm 2.
6   Evaluate population by the newly updated positions.
7   t=t+1.
8 end

```

## Results and discussion

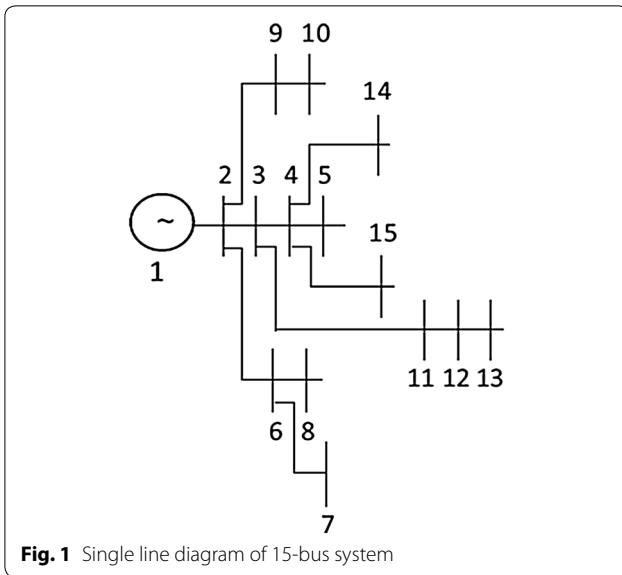
EHO algorithm for the application of DG planning problem to obtain DG size and economic analysis is presented in this section. IEEE 15-, 33- and 69-bus test systems are evaluated using Matlab. The parameters using in EHO algorithm are  $\alpha = 0.5$ ,  $\beta = 0.1$ , popsize = 50, Maxgen = 60.

### Techno-economic analysis

The real and reactive power loss, minimum voltage level and the cost of energy loss as well as cost of power obtained from DGs have been provided for 15-, 33- and 69-bus test systems at unity and 0.9 pf lag with comparisons. The cost of energy losses and cost component of DG power has been calculated based on the mathematical model represented as

### Cost of energy losses (CL)

The annual cost of energy loss is given by (Murthy and Kumar 2013; Suresh and Belwin 2018)



**Fig. 1** Single line diagram of 15-bus system

$$CL = (TPL) * (Kp + Ke * Lsf * 8760) \$ \tag{9}$$

where TPL: total real power losses, Kp: annual demand cost of power loss (\$/kW), Ke: annual cost of energy loss (\$/kW h) and Lsf: loss factor.

Loss factor is expressed in terms of load factor (Lf) as below

$$Lsf = k * Lf + (1 - k) * Lf^2 \tag{10}$$

The values taken for the coefficients in the loss factor calculation are:  $k = 0.2$ ,  $Lf = 0.47$ ,  $Kp = 57.6923 \text{ \$/kW}$ ,  $Ke = 0.00961538 \text{ \$/kWh}$ .

**Cost component of DG for real and reactive power**

$$C(Pdg) = a * Pdg^2 + b * Pdg + c \text{ \$/MWh} \tag{11}$$

Cost coefficients are taken as:  $a = 0$ ,  $b = 20$ ,  $c = 0.25$ .

Cost of reactive power supplied by DG is calculated based on maximum complex power supplied by DG as

$$C(Qdg) = [Cost(Sg \max) - Cost(\sqrt{Sg \max^2 - Qg^2})] * k \tag{12}$$

$$Sg \max = \frac{Pg \max}{\cos \phi} \tag{13}$$

$Pg \max = 1.1 * pg$ , the power factor, has been taken 1 at unity power factor and 0.9(lag) at lagging power factor to carry out the analysis.  $k = 0.05 - 0.1$ . In this paper, the value of factor  $k$  is taken as 0.1.

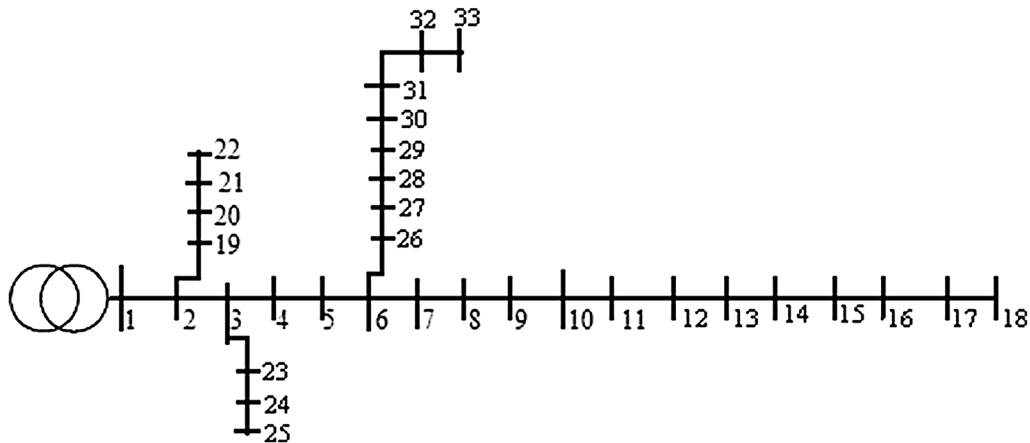
**IEEE 15-bus system**

The single line diagram of IEEE 15-bus distribution system (Baran and Wu 1989) is shown in Fig. 1.

For IEEE 15-bus system without installation of DG, the real and reactive power losses are 61.7933 kW and 57.2969 kVAR, respectively. With the installation of DG at unity pf real, reactive power losses are 42.24 kW and 39.99 kVAR, respectively. With DG installation operating at 0.9 pf lag, the real and reactive power losses are 28.05 kW and 22.94 kVAR, respectively. Comparison of results is shown in Table 4. The optimal location for 15-bus test system is 15. The minimum voltage is more in case of type III DG operating at 0.9 pf. The losses are also lower with DG type III operating at 0.9 pf lag when compared to DG operating at upf. This is because both real and reactive powers are supplied by the DG at lagging pf. Reactive power is not supplied by type III DG when operating at unity pf. Hence losses are higher when compared to DG operating at 0.9 pf lagging. The cost of energy losses, cost of PDG and cost of QDG are shown in Table 4. From the table, the cost of energy losses is reduced from 4970.3 \$ to 2256 \$ when DG is operating at 0.9 pf lag and it is reduced to 3397 \$ when operating at unity pf. Cost of energy losses are less when DG is operating at 0.9 pf. When compared with the method

**Table 4 Results for 15-bus system**

	Without DG	With DG at 0.9 pf (Dinakara Prasad Reddy et al. 2017)	Proposed method at 0.9 pf	With DG at UPF (Dinakara Prasad Reddy et al. 2017)	Proposed method at upf
DG location	–	6	15	6	15
DG size (kVA)	–	907.785	910.5	675.248	681.1
TLP (kW)	61.7933	33.385	28.05	45.8035	42.24
TLR (kVAR)	57.2969	29.89	22.94	41.88	39.99
Vmin (p.u.)	0.9445	0.959	0.971	0.9527	0.9596
Cost of energy losses (\$)	4970.3	2685.31	2256	3684.18	3397
Cost of PDG (\$/MW h)	–	16.5404	16.598	13.754	13.87
Cost of QDG (\$/MVAR h)	–	1.8656	1.872	–	–



**Fig. 2** Single line diagram of 33-bus system

(Dinakara Prasad Reddy et al. 2017), the proposed power loss reduction combined with EHO algorithms gives better results.

**Results for 33-bus distribution system**

The single line diagram of IEEE 33-bus distribution system (Baran and Wu 1989) is shown in Fig. 2.

For 33-bus system without installation of DG, the real and reactive power losses are 211 kW and 143 kVAR, respectively. The real and reactive power from the

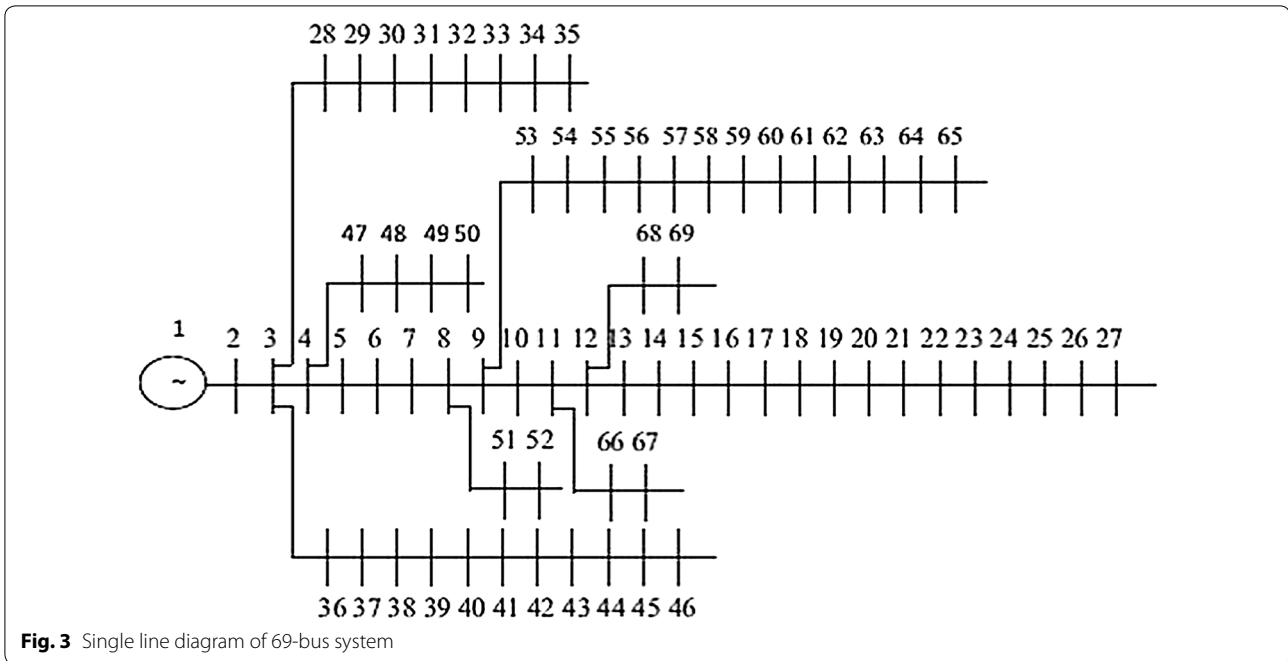
substation is 3926 kW and 2443 kVAR. With installation of DG at unity pf, the real and reactive power losses are 125 kW and 89.3 kVAR, respectively. Also the real and reactive power from the substation is decreased to 2375 kW and 2443 kVAR. With DG operating at 0.9 pf lag, the real and reactive power losses are 78.4 kW and 58.97 kVAR, respectively. The real and reactive powers from the substation become 218 kW and 1593 kVAR. The cost of energy losses, cost of PDG and cost of QDG are also shown in Tables 5 and 6. From table, the cost of energy

**Table 5 Results for 33-bus system with DG at upf**

	Without DG	Method (Murthy and Kumar 2013)	Method in Dinakara Prasad Reddy et al. (2017)	Proposed method
DG location	–	16	6	30
DG size (kW)	–	1000	2590.2	1544.5
Total real power loss (TLP) (kW)	211	136.7533	111.0338	125.2
Total reactive power (TLR) loss (kVAR)	143	92.6599	81.6859	89.3
Vmin (p.u.)	0.904	0.9318	0.9424	0.9272
Cost of energy losses (\$)	16982.6	11,007.9	8930.65	10,067.3
Cost of PDG (\$/MW h)	–	20.25	52.05	31.15

**Table 6 Results for 33-bus system with DG at 0.9 pf**

	Method (Murthy and Kumar 2013)	Method in Dinakara Prasad Reddy et al. (2017)	Proposed method
DG location	16	6	30
DG size (kVA)	1200	3073.5	1939.3
TLP (kW)	112.7864	70.8652	78.4
TLR (kVAR)	77.449	56.7703	58.97
Vmin (p.u.)	0.9378	0.9566	0.9386
Cost of energy losses (\$)	9078.7686	5700.01	6308.8
Cost of PDG (\$/MW h)	21.85	55.5	35.102
Cost of QDG (\$/MVAR h)	2.1207	6.2	3.928



**Fig. 3** Single line diagram of 69-bus system

**Table 7 Results for 69-bus system with DG at upf**

	Without DG	Method (Murthy and Kumar 2013)	Method in Dinakara Prasad Reddy et al. (2017)	Proposed method
DG location	–	65	61	61
DG size (kW)	–	1450	1872.7	1873.6
TLP (kW)	225	112.0217	83.22	83.23
TLR (kVAR)	102.1091	55.1172	40.57	40.54
Vmin (p.u.)	0.909253	0.9660621	0.9685	0.9683
Cost of energy losses (\$)	18,101.7621	9017.2139	6694	6693.8
Cost of Pdg (\$/MW h)	–	29.25	37.7	37.73

losses is reduced from 16982.57 \$ to 6308.8 \$ when DG is operating at 0.9 pf lag and it reduced to 10067.3 \$ when operating at unity pf. Cost of energy losses is less when DG is operating at 0.9 pf. When compared with Murthy and Kumar (2013), the proposed method gives better results.

**Results for 69-bus distribution system**

The IEEE 69-bus distribution system with 12.66-kV base voltage (Baran and Wu 1989) is shown in Fig. 3.

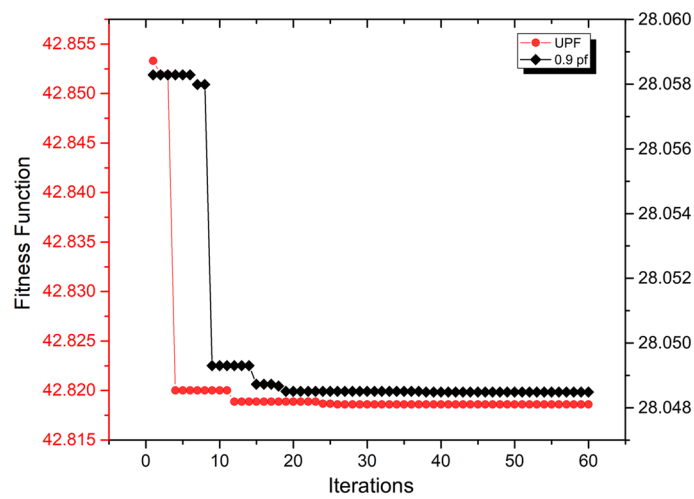
Without DG installation, the real and reactive power losses are 225 kW and 102.1091 kVAR, respectively. With

the installation of DG at unity pf, the real and reactive power losses are 83.2261 kW and 40.54 kVAR, respectively. With DG operating at 0.9 pf lag, the real and reactive power losses are 27.95 kW and 16.46 kVAR.

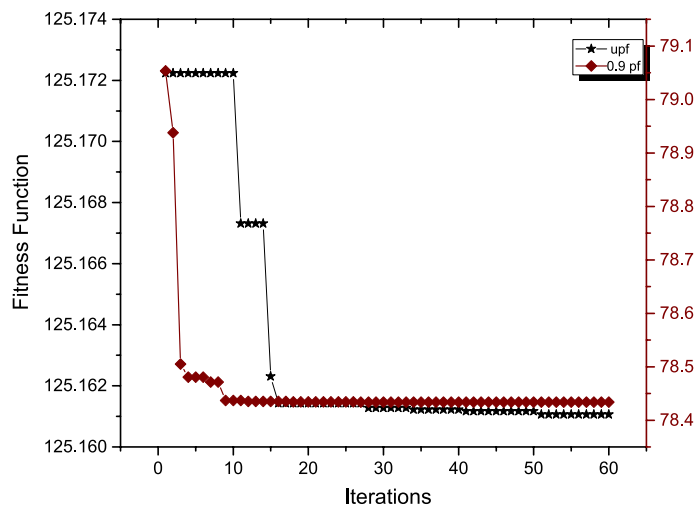
The losses obtained are lower when DG operating at lagging power factor when compared to unity power factor DG. This is due to reactive power available in lagging power factor DG. The cost of energy losses, cost of PDG and cost of QDG are also shown in Tables 5 and 6. From table the cost of energy losses is reduced from 18,101.7 \$ to 2249.4 \$ when DG is operating at 0.9 pf lag and it reduced to 6693.8 \$ when operating at unity pf. The cost of energy losses are less when DG is operating at 0.9 pf.

**Table 8 Results for 69-bus system with DG at 0.9 pf**

	Method (Murthy and Kumar 2013)	Method in Dinakara Prasad Reddy et al. (2017)	Proposed method
DG location	65	61	61
DG size (kVA)	1750	2217.3	2216.3
TLP (kW)	65.4502	27.9636	27.95
TLR (kVAR)	35.625	16.4979	16.46
Vmin (p.u.)	0.969302	0.9728	0.9724
Cost of energy losses (\$)	5268.4297	2249.2	2249.4
Cost of PDG (\$/MW h)	31.75	40.1	40.0916
Cost of QDG (\$/MVAR h)	3.083	4.48	4.4824

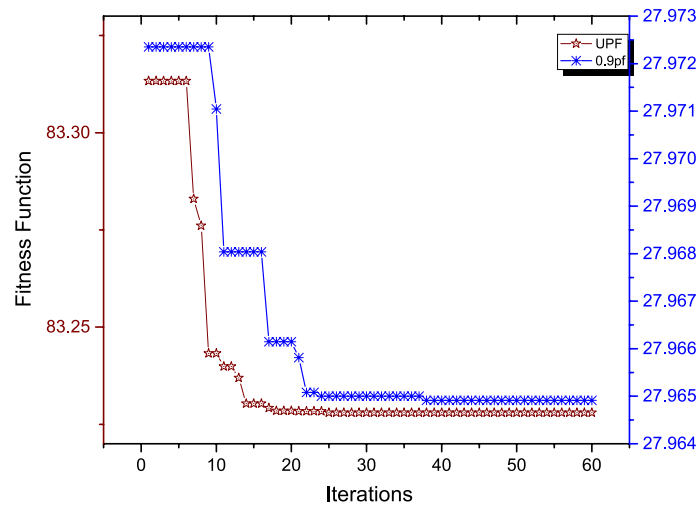


**Fig. 4** Convergence characteristics of 15-bus system

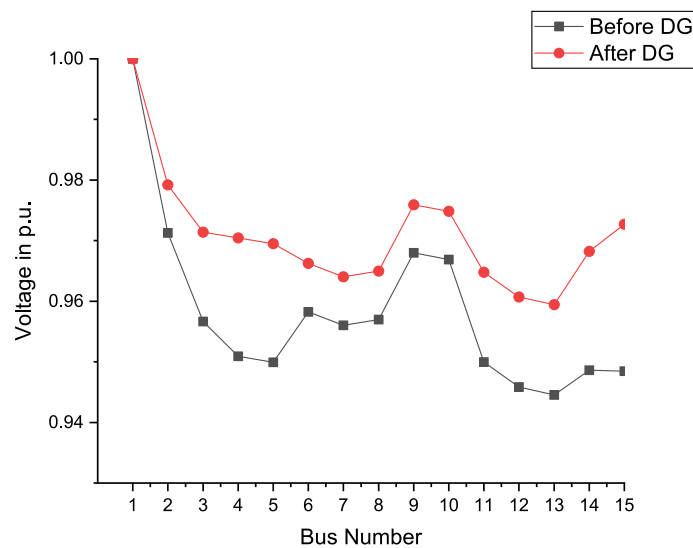


**Fig. 5** Convergence characteristics of 33-bus system





**Fig. 6** Convergence characteristics of 69-bus system



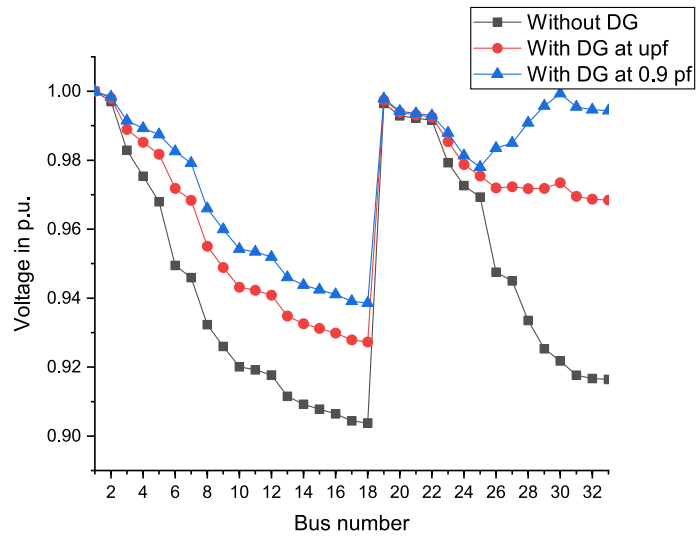
**Fig. 7** Voltage profile of 15-bus system

The results obtained are given in Tables 7 and 8. Better results are obtained while considering reactive power of DG when comparison with unity pf. Convergence characteristics of EHO algorithm for IEEE test systems with upf and 0.9 pf are shown in Figs. 4, 5 and 6, respectively.

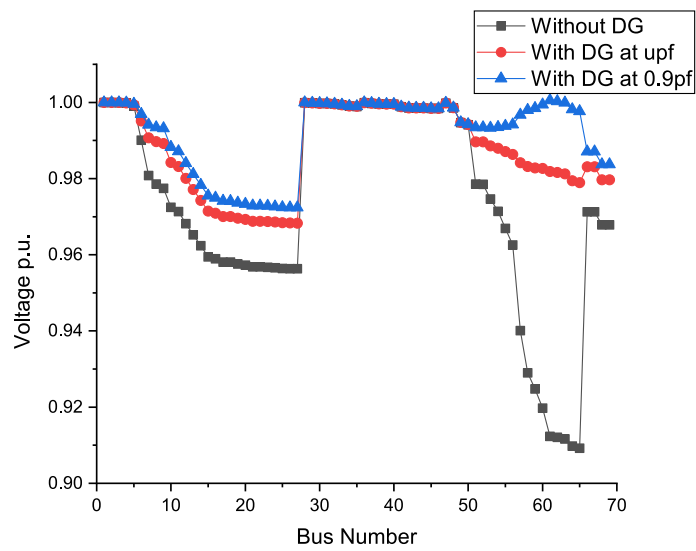
The voltage profile is also improved with DGs at lagging power factor, and it is shown in Figs. 7, 8 and 9. The voltage profile obtained for the system with DG operating at 0.9 pf is better compared to the voltage profile obtained with DGs at unity power factor. The power loss comparison is shown in Fig. 10.

### Conclusions

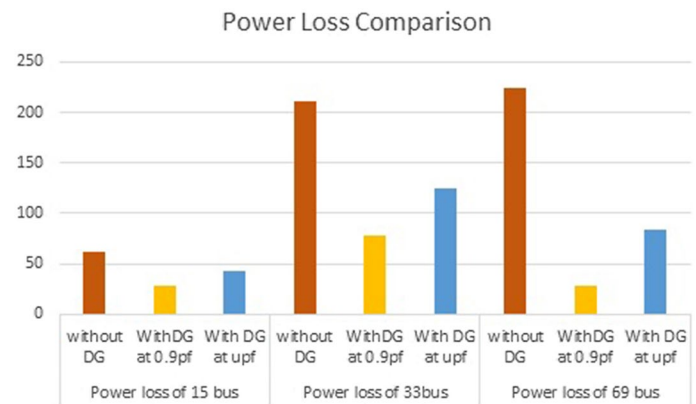
In this paper, a novel nature-inspired algorithm called elephant herding optimization is used to determine the optimal DG unit's size. It has been developed based on herding behaviour of elephant groups in nature. The study is carried out on two types of DG that are DG operating at unity power factor and DG operating at 0.9 power factor lag. The results have been obtained for real and reactive power losses, voltage profile, cost component for real power and reactive power obtained from



**Fig. 8** Voltage profile of 33-bus system



**Fig. 9** Voltage profile of 69-bus system



**Fig. 10** Power loss comparison

DGs, and their sizes. We can conclude that there is much reduction in real, reactive power losses and improvement in voltage profile with DG at 0.9 pf lag due to its reactive power supply to the system. Therefore, DG operating at lagging power factor and supplying reactive power to the system is giving better results than DG at unity power factor. From the results, it can be concluded that with the combination of power loss index method and EHO algorithm is giving overall better results when compared with other algorithms.

#### Abbreviations

$\alpha$ : Scale factor;  $D$ : Dimension; Maxgen: Maximum generations; TPL: Total real power losses; Kp: Annual demand cost of power loss (\$/kW); Ke: Annual cost of energy loss (\$/kW h); Lsf: Loss factor.

#### Authors' contributions

CHP carried out the literature survey and participated in DG location section. CHP and KS participated in the study on different nature-inspired algorithms for DG sizing. CHP carried out the DG sizing algorithm design and mathematical modelling. CHP, KS and PS participated in the assessment of the study and performed the analysis. CHP and PS participated in the sequence alignment and drafted the manuscript. All authors read and approved the final manuscript.

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#### Competing interests

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